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(12) UK Patent Application (19) GB (11) 2 268 138 (13) A

(43) Date of A Publication 05.01.1994

(21) Application No 8119086.0

(22) Date of Filing 20.06.1981

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(51) INT CL^5
B64C 29/00 15/02 , B64D 27/18 // B64C 39/08

(52) UK CL (Edition M)
B7G GDAA GJAJ GJVN G401
B7W WPF W611

(56) Documents Cited
None

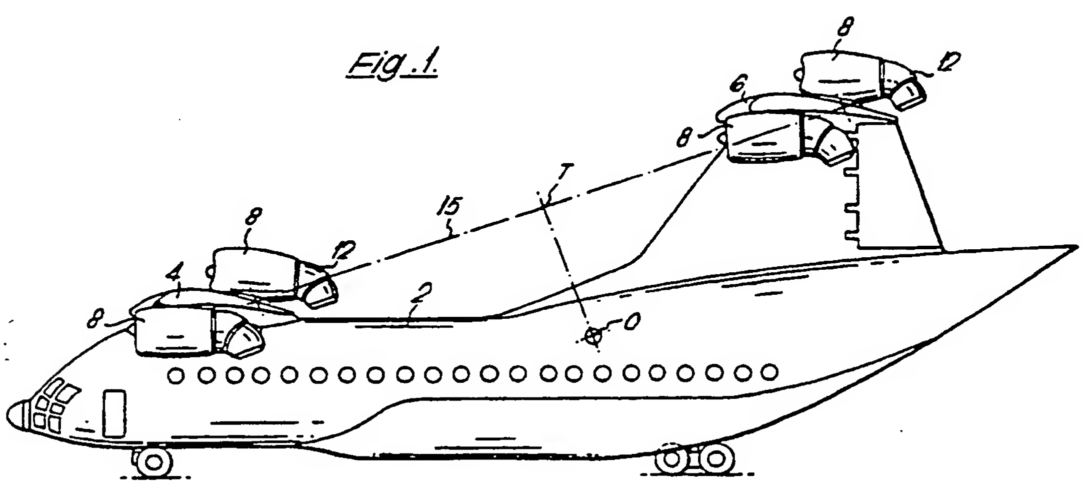
(58) Field of Search
UK CL (Edition C) B7G

(54) **Multi-engined VTOL aircraft**

(57) In a multi-engined VTOL aircraft the out-of-balance thrust produced by an engine failure during vertical take-off is countered by vectoring the thrust of the remaining engines in both the transverse and fore and aft planes to keep the thrust vertical whatever the aircraft attitude.

As described, the aircraft has eight engines 8 mounted on wings 4 and 6 and each engine 8 has a nozzle 12 from which the engine thrust can be directed with rearward and downward components of velocity. The centre of the lifting thrust is arranged to be above the aircraft centre of gravity so that the aircraft will pitch and roll only until the centre of gravity lies below the new lift thrust centre and will then stabilise in a tilted attitude. A general mathematical theorem is discussed which indicates the constraints on the positioning of the engines on the aircraft, and the requirements for an automatic control system are outlined.

Fig. 1.



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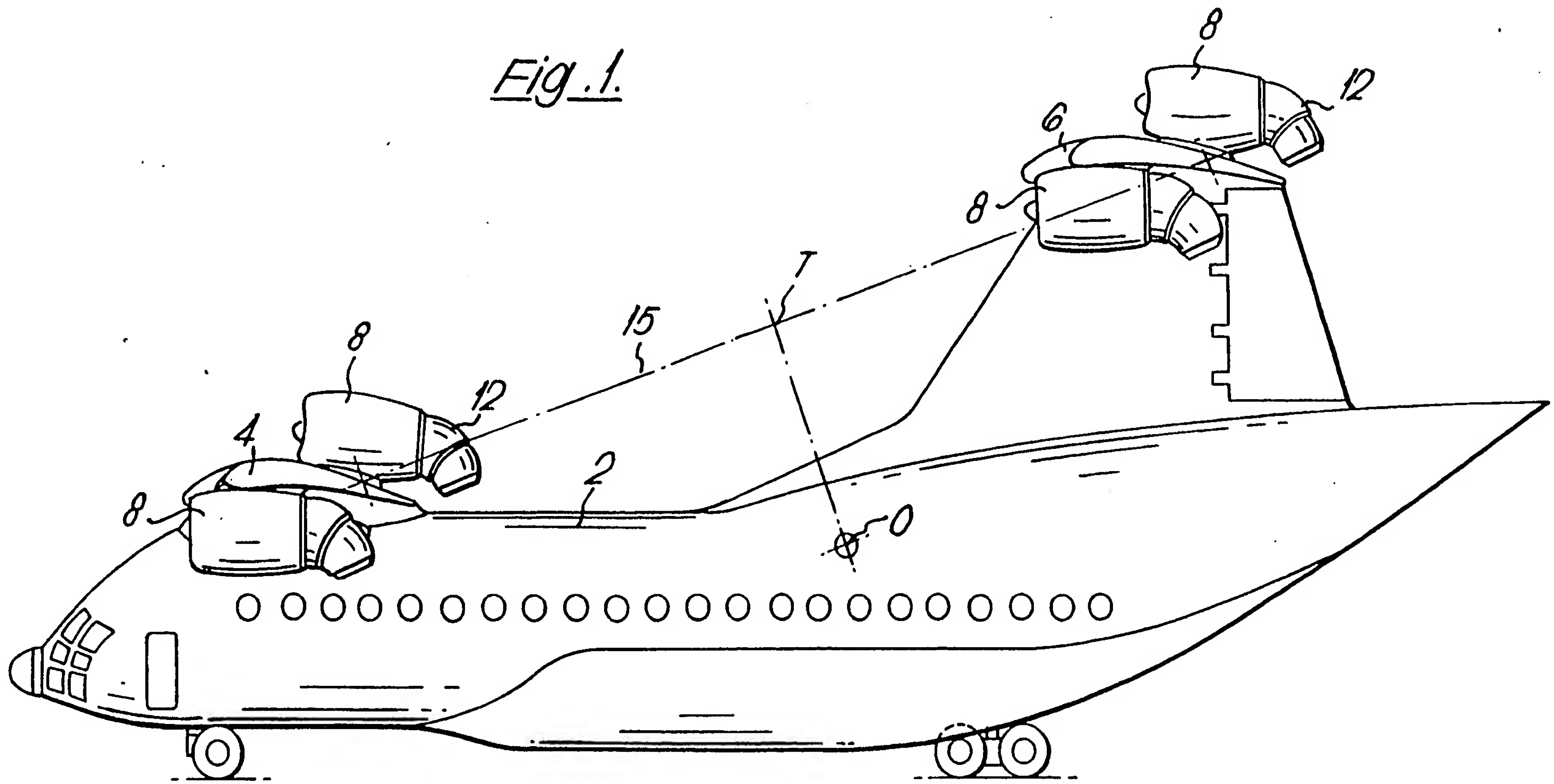
At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1.



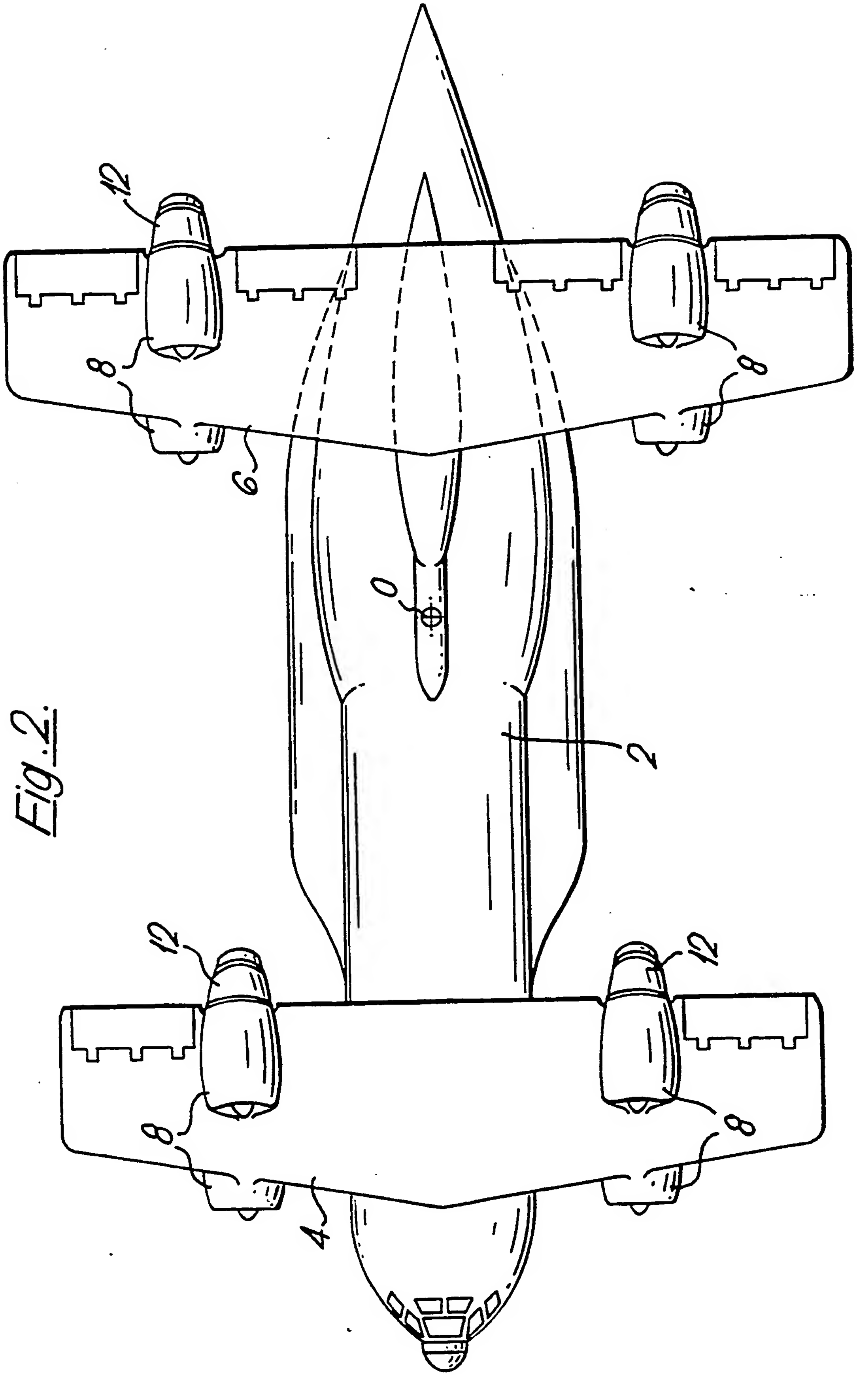


Fig.2.

Fig. 3.

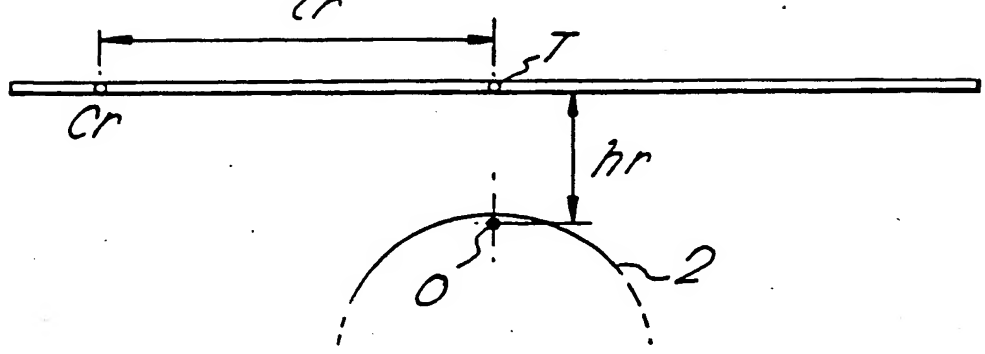


Fig. 4.

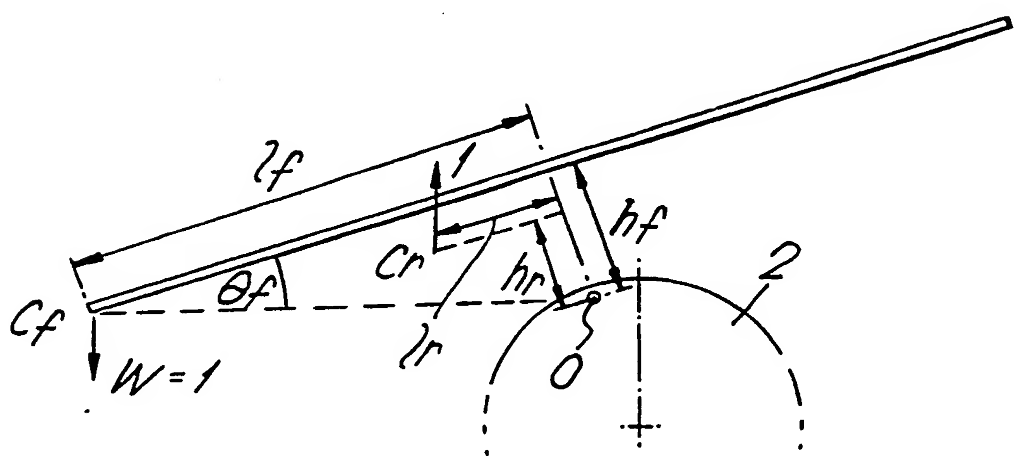
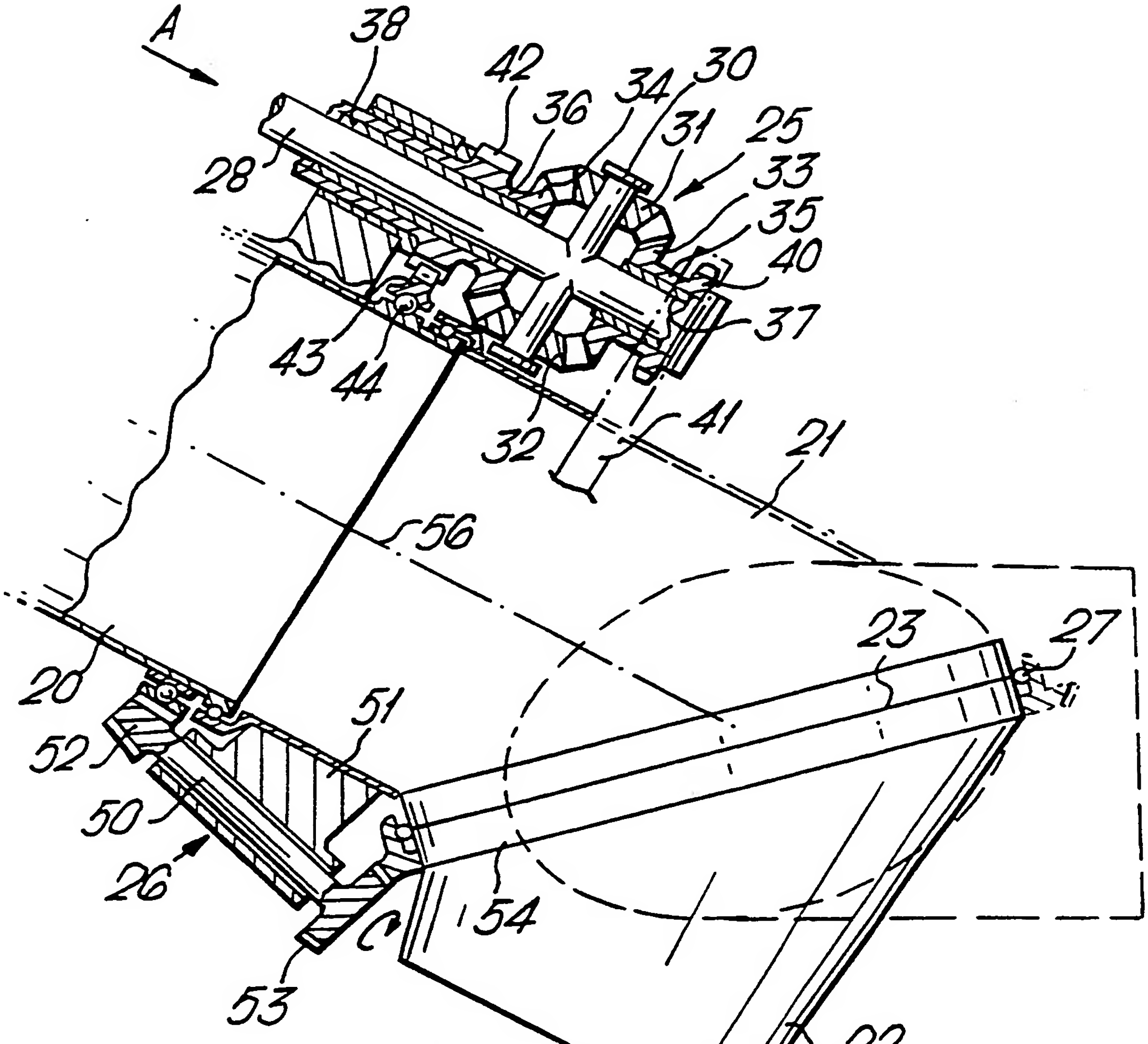


Fig. 5.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MULTI-ENGINED VTOL AIRCRAFT

The present invention relates to a multi-engined aircraft which is capable of taking off and landing vertically. Such aircraft are commonly referred to as VTOL aircraft.

One fundamental problem which exists with a multi-engined VTOL aircraft is that if an engine fails during the vertical mode of operation the loss of thrust produces pitch and roll moments on the aircraft which could turn the aircraft over.

Several solutions have been proposed to overcome this problem but none has so far resulted in a practical aircraft. One solution, in a twin-engined installation, has been to arrange for each engine to have front and rear exhausts and to provide four nozzles symmetrically placed on opposite sides of the aircraft centre of gravity. By connecting the front exhaust to a front nozzle on one side of the aircraft, and the rear exhaust to a rear nozzle on the other side of the aircraft, the thrusts on each side do not become unbalanced if an engine fails. The provision of cross-over ducting for this purpose, however, produces a heavy aircraft.

An alternative solution was to have a large number of small lift engines symmetrically placed around the aircraft centre of gravity. In this case if one engine failed a second, in a symmetrically opposite position, was shut down to eliminate the out of balance thrust.

This latter solution is only possible where the additional loss of lift occurring due to the shutting down of a second engine still leaves sufficient lift available with the remaining engines operating at their emergency rating, to allow the aircraft to make an emergency landing.

One object of the present invention is to provide a multi-engined VTOL aircraft which solves the problem of vertical operation with one or more engines failed without the disadvantages of the above-described earlier proposed solutions.

Another object of the present invention is to provide a VTOL aircraft which uses jet lift and which can improve on the payload and range of the best current helicopter design.

According to the present invention a multi-engined VTOL aircraft comprises a plurality of engines capable of producing the required lifting and forward propulsion thrusts on the aircraft and is characterised in that the engines are so arranged that the centre of the total lifting thrust is above the aircraft centre of gravity, and that the thrust of each of the lift-producing engines is vectorable in the transverse and the fore and aft planes so that it is capable of being directed downwardly whatever the attitude of the aircraft.

By this means it is possible, when one of the engine fails in a vertical mode of operation of the aircraft and the aircraft begins to roll or pitch, to vector the thrust of the other engines in the transverse and fore and aft planes, to restore the thrust to the vertical and thus to prevent the rolling and pitching moments, due to the unbalanced thrust on one side of the aircraft, from overturning the aircraft. Thus the aircraft will roll and pitch only until its centre of gravity lies below the new centre of lift and the balance of moments about the centre of gravity is restored.

Clearly there are many variations possible in the manner in which the invention is carried into effect. For example, the engines used may provide lift only, forward propulsion only, or may be of the vectored thrust type which provide both lift and forward propulsion, and they may be provided in any appropriate mixture and arrangement suitable for the particular requirements of the aircraft.

In preferred forms of the invention there are provided at least four, and preferably eight, engines all of the same vectored thrust type, capable of producing both horizontal and vertical thrust, thus providing for simplicity of operation and commonality of parts. The engines are also preferably placed symmetrically about the aircraft planform or, where complete symmetry is not possible each one should have a corresponding one positioned as a mirror image at least on the opposite side of the roll axis of the aircraft. Thus, for example, if the chosen engines are not all of the same thrust, they must be arranged so that the moments they provide on the aircraft balance about the centre of gravity of the aircraft.

The invention will now be more particularly described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is an elevation of a practical aircraft embodying the invention,

Fig. 2 is a plan view of the aircraft of Fig. 2,

Fig. 3 and 4 illustrate diagrammatically end views of an aircraft of the present invention, in the normal and tilted positions respectively, and,

Fig. 5 is a side elevation of a vectorable nozzle and actuating mechanism for the engines of the aircraft of Figs. 1 and 2..

Referring now to Figs. 1 and 2 of the drawings, there is shown an aircraft having a fuselage 2, and two engine support structures 4 and 6 which take the form of lifting wings. Eight engines 8 are mounted on the wings 4 and 6 in a pattern around the centre of gravity O of the aircraft. The engines are provided with vectorable nozzles 12 and are capable of providing both upward and forward thrust. As an alternative, however, the engines may be pivotably mounted.

The engines are mounted in an arrangement such that the centre T of the lifting thrust applied to the aircraft is significantly above the centre of gravity of the aircraft, and, apart from being capable of providing upward and forward thrust, the direction of thrust of each engine is also arranged to be vectorable in the

transverse plane so that it remains vertical whatever the attitude of the aircraft. In the particular example shown, the aircraft tilts on its rear wheels at take-off until the mean plane of thrust 15 is horizontal and the point T is vertically above the centre of gravity O.

Thus it can be seen that should an engine fail, the centre of lift T will move and the aircraft will be unbalanced. Provided, however, that the thrust of each of the remaining engines is constantly controlled to remain vertical regardless of the aircraft attitude, the aircraft will only tilt until the vertical forces balance once again about the aircraft centre of gravity. This is achieved when the aircraft centre of gravity lies beneath the new centre of lift.

Hence the aircraft will stabilise in an inclined attitude giving the pilot the opportunity either to continue with a vertical landing, or to increase forward speed to regain lift on the wings and to make a traditional wingborn landing instead of a vertical landing.

The engine layout for such an aircraft will depend upon the relative importance of the pitch to roll attitude. Where they are both of equal importance then a possible arrangement of the engines will be one in which they are equally pitched around a circle centred on the centre of gravity of the aircraft.

However, since aircraft passengers are more used to variations in pitch during take-off and landing, it may be preferable to group the engines together in a configuration which minimises the unfamiliar rolling moments produced on engine failure.

In order to examine the limitations of the invention as applied to a practical aircraft design, it is worthwhile to analyse very briefly the forces acting on the aircraft, for which it is necessary to refer to Figs. 3 and 4.

Consider an aircraft having N installed lifting engines denoted by the suffices 1, 2, ...N. Let any engine "r" have its thrust rotation centre located at Cr, and let the position of Cr be defined at a height hr above, and at a distance lr from the centre of gravity O of the aircraft. This is shown in Fig. 3.

Now consider the case of an engine "f" having failed. Both pitching and rolling moments will be produced and the aircraft will tilt about a horizontal axis perpendicular to the plane containing O and Cf which will lie at an angle to both the pitch and roll axes. By transversely vectoring the thrust of the remaining engines so that their thrust remains vertical, the aircraft will stabilise after tilting through an angle θf as shown in Fig. 4. For the purposes of the following analysis it is assumed that all N engines continue to operate at an emergency thrust rating, and the engine failure is simulated by adding a weight W at Cf equal to the unit emergency thrust. Then taking moments about a horizontal axis perpendicular to the plane containing OCf we can write:

$$lf \cos \theta f + hf \sin \theta f = \sum_{r=1}^{n} (lr \cos \theta f + hf \sin \theta f)$$

If we put $\sum_{r=1}^{n} hr = N\bar{h}$ where $\bar{h}$ is the average height of the engines above the aircraft centre of gravity, and noting that $\sum_{r=1}^{n} lr = 0$, it follows that:

$$\frac{lf}{\bar{h}} = \left(N - \frac{hf}{\bar{h}}\right) \tan \theta f$$

By putting various practical assumptions into this general theorem some of the limitations affecting the aircraft design can be explored.

For example, a practical range of tilting angles would be between 20° and 30° in a passenger carrying aircraft.

From the general theorem it is clear that, the maximum practical tilt angle puts a limitation on the value of $\frac{l}{h}$. Another limitation is the possibility of the exhausts from some of the lift engines interfering with the aircraft fuselage, when their thrust is vectored transversely to keep the lifting thrust vertical in the case of an engine failure. The loss of lift which occurs when the jet interferes with the fuselage is very significant so that the avoidance of interference is a very important design consideration. In order to check the design it is necessary first of all to calculate from the basic theorem the angle of tilt θf caused by the failed engine. Then the maximum angles through which the lifting thrust of the remaining engines can be turned towards the fuselage without interference is calculated bearing in mind the fact that the jet spreads laterally from the nozzle exit. If it is found that interference occurs the layout of the engines has to be re-arranged. Where a satisfactory arrangement of engines cannot be produced with the limitation that the thrust of the lifting engines should remain vertical in the transverse plane, it is within the scope of the present invention that the degree of thrust vectoring of different engines may be different, in either

the fore and aft plane, or the transverse plane, in order to maximise the total vertical thrust while balancing all of the forces and moments. In any case some differential thrust vectoring may be beneficial in different modes of operation of the aircraft, to alleviate the jet interference problem described above, or, for example, to provide pitch and roll control.

Another consideration is that where the aircraft is provided with wings to produce lift in the cruise mode of operation, only a fraction of the number of engines will be needed for forward propulsion. This provides a choice as to whether or not the remaining engines should be shut down or kept operating. The optimum solution may be different for different aircraft requirements but the following considerations apply:

i) Although the superfluous engines, if shut down, would not be using fuel, there would be a significant momentum drag from air entering the engines. This could be offset by running the engines continuously at low power.

ii) The problems involved in re-lighting say six out of eight engines at the end of each flight may not be acceptable.

iii) The engines used for forward propulsion are preferably mounted as near the centre of gravity as possible in order to minimise the pitching moments produced when the engine thrust line passes through the centre of gravity. However, where an aircraft does suffer from significant pitching moments due to this cause, it may be an advantage to keep at least some of the superfluous lift engines running to provide a balancing lift thrust.

iv) If the superfluous lift engines are kept running they could be used for control of any other moments in the pitch and roll planes so that additional control systems, e.g. ailerons or puffer jets would not be necessary.

Further analysis of the various aircraft limitations and possible engine arrangements leads to the following features being included in the aircraft layout as shown in Figs. 1 and 2.

The eight engines 8 are mounted in four pairs on the wings with one engine of each pair above and one below the wing. The four pairs of engines lie on the corners of a substantially rectangular figure having one axis parallel to the longitudinal axis of the aircraft fuselage 2 and passing through the aircraft centre of gravity O.

Two pairs of engines are mounted forward of, and two pairs are mounted aft of the aircraft centre of gravity O to provide pitch control, but the angle between the diagonals of the rectangle should be as small as possible to minimise the jet interference problem. The two most forwardly mounted engines only are used to provide the greater part of the forward thrust, and they are mounted as far forward and as low as possible to minimise fuel consumption, and to allow wings 4 and 6 to provide the greater part of the lift in forward flight.

The six remaining engines are arranged to be continuously operated and each is mounted with the longitudinal axis of the jet pipe inclined to the longitudinal axis of the fuselage 2. Thus even when the

nozzle axis and jet pipe axis are aligned in the cruise mode of operation of the aircraft, there will be an upward component of the thrust available for control purposes in addition to the horizontal component. One advantage of this inclination of the engine thrust axis is that less rotation of the nozzle is required to produce vertical thrust, and by rotating the nozzle further some forward thrust can be produced for producing a braking effect.

One possible mechanism for providing both fore and aft and transverse vectoring of the engine thrust is shown in Fig. 5 of the drawings. The engine nozzle includes a fixed duct 20 and two rotatable ducts 21 and 22 which abut at a joint 23 which is scarfed in a transverse plane. Rotation of the ducts 21 and 22 from the forward thrust position (shown dotted) to the vertical thrust position is achieved with a differential gear drive having two differential gears 25 and 26 shown on opposite sides of the fixed duct, and a bearing 27 provides support for the rotation.

The differential gear 25 is carried on a pitch control shaft 28, and includes a pin 30 which carries bevel gears 31 and 32 at each end. Bevel gears 31 and 32 both mesh with bevel gears 33 and 34 carried on shafts 35 and 36 which, in turn, are mounted on bearings 37 and 38 respectively for rotation relative to shaft 28.

Shaft 35 also carries a sprocket wheel 40 which is engaged by a chain 41 which is connected at its ends to the duct 21 for rotating the duct. Shaft 36, which is the roll control shaft, also carries a spur gear 42 which meshes with a ring gear 43 mounted for rotation on the fixed duct 20 by means of a bearing 44.

The differential gear 26 consists of a shaft 50 mounted on a carriage 51 on the duct 21. The shaft 50 has a bevel gear 52 at one end which meshes with the ring gear 43, and a spur gear 53 at the other end which meshes with a toothed rack 54 on the duct 22.

In order to move the nozzle in a vertical plane to change the pitching moments on the aircraft and to change from vertical to horizontal thrust from the engines, the pitch control shaft 28 is rotated. Assuming shaft 28 is rotated clockwise viewed in the direction of arrow A, and the roll control shaft 36 is fixed, the pin 30 will be rotated clockwise and bevel gear 33 will be rotated anti-clockwise due to the bevel gears 31 and 32 rolling around the bevel gear 34. Hence the sprocket wheel 40 will drive the chain 41 anti-clockwise and produce an anti-clockwise rotation of duct 21. Rotation of duct 21 rotates the carriage 51 and shaft 50 anti-clockwise about the axis 56 of duct 21, and since ring gear 43 is held fixed by shaft 36, bevel gear 52 will roll around the ring gear 42 rotating the shaft 50 anti-clockwise about its own axis together with spur gear 53. The duct 22 is thus rotated clockwise about its axis due to meshing of the gear 53 with the rack 54. The angle through which duct 22 is rotated is arranged, by choosing the gear ratio between gears 52 and 53, to be twice the angle of rotation of duct 21 using static duct 20 as the reference. The effect is that, if duct 21 rotates through n degrees anti-clockwise, duct 22 will rotate n degrees clockwise relative to duct 21, and due to the effect of the scarfed joint 23 the thrust from duct 22 will move from vertical to horizontal in a vertical plane with no sideways deflection.

To provide roll control the shaft 36 is rotated and the effect can be best described assuming that during this mode of operation the shaft 28 is fixed. Assuming again that shaft 36 rotates clockwise seen in the direction of arrow A the rotation of the bevel gear 34 on the shaft 36 will cause an anti-clockwise rotation of bevel gear 33 and hence an anti-clockwise rotation of duct 21 through the sprocket and chain arrangement. Now, however, spur gear 42 on shaft 36 will rotate the ring gear 43 anti-clockwise, and the drive ratios of spur gear 42 and sprocket wheel 40 are arranged to be the same, so that the rotations of the ring gear 43 and the duct 21 with the carriage 51 are the same. Thus there will be no rotation of bevels 52 and 53 and no relative rotation between ducts 21 and 22. Both ducts 21 and 22 will rotate about axis 56 to vary the direction of thrust in the transverse plane.

In order to ensure that under no circumstances will the nozzles rotate transversely to a position in which the jet interferes with the aircraft, a positive stop is introduced which prevents rotation of the nozzle beyond a given point.

Depending on the numbers and dispositions of the engines around an aircraft, the angle of the duct axis may be canted downwards to produce sufficient pitch angle in the vertical mode of operation to cater for the worst anticipated failure mode.

Clearly there are many alternative operating mechanisms for producing the required nozzle movements, not all of which can be described herein. However, one possible alternative would be to have separate mechanisms for pitch and roll control. One alternative pitch control mechanism is described in our co-pending patent application No. 8111454, and to this could be added a simple gear drive to additionally rotate the duct 20, while the pitch mechanism remains locked, to provide transverse orientation of the thrust.

With the number of engines envisaged in the above-described aircraft, account has to be taken of a double engine failure. Although the thrust vectoring of the engines described should be capable of stabilising the aircraft with a second engine failed, the angle of tilt may well be unacceptable for continued flight without further compensation of the pitch and roll moments. Provision may, therefore, be made for pumping fuel, or other ballast, between compartments in the aircraft to produce balancing moments to reduce the tilt angle to a more acceptable level. In some cases it may be possible to arrange for some of the payload to be ditched to lighten the aircraft to allow for thrust reductions to be made in symmetrically opposite engines to minimise the tilt angle.

Another fundamental consideration is the provision of an automatic control system to control the nozzles for providing the necessary balancing moments. Such a system will inevitably include attitude sensors to detect tilting of the aircraft in both the pitch and roll planes, position sensors on the nozzles to determine the angles of their thrusts in the pitch and roll planes, and thrust sensors to determine the magnitude of the nozzle thrusts.

A computer will be required programmed to receive these signals as inputs along with other inputs indicating, for example, the aircraft centre of gravity position, to calculate the optimum manner in which stability can be restored and to send appropriate signals to the nozzle drive motors. The computer will determine, for example, which engines should be vectored for optimum effect, and by how much. The mechanical elements, e.g. the sensors and motors, required for such a system are currently available, and many combinations and arrangements of the elements may be devised. Since the actual design of the control system is not a part of the present invention, none is described in detail in this specification.

CLAIMS

1. A multi-engined VTOL aircraft comprising a plurality of engines capable of producing the required lifting and forward propulsion thrusts on the aircraft and characterised in that the engines are so arranged that the centre of the total lifting thrust is above the aircraft centre of gravity, and in that the lifting thrust is vectorable in the transverse and the fore and aft planes so that it is capable of being directed downwardly whatever the attitude of the aircraft.

2. A multi-engined VTOL aircraft as claimed in Claim 1 and in which each of the engines has a vectorable nozzle capable of vectoring the thrust between directions in which the forward thrust component is predominant and in which the lifting thrust component is predominant.

3. A multi-engined VTOL aircraft as claimed in Claim 2 and in which the nozzle is additionally vectorable in a transverse plane so as to be capable of producing vertical thrust when the aircraft is tilted about its roll axis.

4. A multi-engined VTOL aircraft as claimed in any preceding claim and in which a stop is included in the transverse vectoring operating mechanism to prevent interference of the jet efflux from the nozzle with the aircraft fuselage.

5. A multi-engined VTOL aircraft as claimed in any preceding claim and in which a control system is provided for automatically vectoring the thrust of appropriate engines in the pitch and roll planes after failure of one or more engines in order to maintain the aircraft in balance.

6. A multi-engined VTOL aircraft as claimed in Claim 5 and in which the control system includes, attitude sensors to sense tilting of the aircraft in the pitch and roll planes, position sensors on the engines to indicate the angle of the engine thrust in the pitch and roll planes, thrust sensors to determine the magnitudes of the thrusts of the engines, means for indicating the position of the centre of gravity of the aircraft, and a computer programmed to receive signals from the sensors and indicator as inputs and to provide output signals to means for vectoring the thrusts of the various engines to maintain the aircraft balanced in its tilted position.

7. A multi-engined VTOL aircraft as claimed in any preceding claim and in which means are provided for moving the aircraft fuel or other ballast between compartments in the aircraft to provide moments about the aircraft centre of gravity to reduce the angle of tilt of the aircraft.

8. A multi-engined VTOL aircraft as claimed in any preceding claim and in which means are provided for reducing the aircraft weight in the event of an engine failure so that the total lifting thrust required is reduced, and means are provided for reducing the lifting thrust of one or more of the engines to maintain the balance of the aircraft with a minimum tilt angle.

9. A multi-engined VTOL aircraft substantially as hereinbefore described with reference to the accompanying drawings.

Amendments to the claims have been filed as follows

1. A multi-engined VTOL aircraft comprising a plurality of engines capable of producing the required lifting and forward propulsion thrusts on the aircraft and characterised in that the engines are so arranged that the centre of the total lifting thrust is above the aircraft centre of gravity, and in that the lifting thrust is vectorable in transverse and fore and aft planes so that it is capable of being directed downwardly whatever the attitude of the aircraft.

2. A multi-engined VTOL aircraft as claimed in Claim 1 and in which each of the engines has a vectorable nozzle capable of vectoring the thrust between directions in which a forward thrust component is predominant and in which a lifting thrust component is predominant.

3. A multi-engined VTOL aircraft as claimed in Claim 2 and in which the nozzle is additionally vectorable in a transverse plane so as to be capable of producing vertical thrust when the aircraft is tilted about its roll axis.

4. A multi-engined VTOL aircraft as claimed in Claim 3 and in which a stop is included in the transverse vectoring operating mechanism to prevent interference of the jet efflux from the nozzle with the aircraft fuselage.

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Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

GB 8119086

Relevant Technical fields (i) UK Cl (Edition C) B7G (JAJ) (ii) Int Cl (Edition) **Databases** (see over) (i) UK Patent Office (ii)	Search Examiner K E WILLIAMS Date of Search 20 JUNE 1981

Documents considered relevant following a search in respect of claims 1 AT LEAST

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	

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Category	Identity of docume... ..d relevant passages	Relevant to claim(s

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E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

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